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DATA FUSION AND CORRELATION TECHNIQUES TESTBED (DFACTT): ANALYSIS TOOLS FOR EMITTER FIX CLUSTERING AND DOCTRINAL TEMPLATE MATCHING

by

Liana Mikulin and Derek Elsaesser
Electronic Support Measures Section
Electronic Warfare Division

DEFENCE RESEARCH ESTABLISHMENT OTTAWA
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ABSTRACT

The Data Fusion And Correlation Techniques Testbed (DFACTT) was developed at Defence Research Establishment Ottawa to investigate automated analysis processes for Communications Electronic Warfare. The aim is to automate the collection, correlation and fusion of Electronic Warfare (EW) and intelligence data to provide real-time enemy situation estimates and immediate threat warning to the battlefield commander. DFACTT employs integrated command, control, and communication functions to automate the complete EW process. Developed in an object oriented software environment, DFACTT collects, correlates, displays on a topographical map, and stores EW and intelligence data. The main functions of the system include automated sensor data analysis and doctrinal template matching. This document describes advances made in the development of new algorithms and techniques for radio location data analysis and doctrinal template matching.

RÉSUMÉ

Le banc d'essai pour les techniques de fusion de données et de corrélation (DFACTT) fut mis au point au Centre de recherche pour la défense, Ottawa, pour étudier les processus automatisés d'analyse des communications de guerre électronique. Son but est d'automatiser la collecte, la corrélation et la fusion des renseignements et des données de guerre électronique afin d'évaluer, en temps réel, la situation de l'ennemi et d'informer le commandant du champ de bataille des menaces immédiates. DFACTT automatise tout le processus de guerre électronique grâce à l'intégration des fonctions de commande, de contrôle et de communications. DFACTT utilise un langage à objets. Il collecte, corrèle et affiche sur une carte topographique et il emmagasine les renseignements et les données de guerre électronique. Les fonctions principales du système incluent l'analyse automatisée des données des capteurs et l'identification des modèles doctrinaux. Ce document décrit les progrès du développement des nouveaux algorithmes et des techniques d'analyse des données de radio localisation et d'identification des modèles doctrinaux.

EXECUTIVE SUMMARY

The Data Fusion And Correlation Techniques Testbed (DFACTT) was developed at Defence Research Establishment Ottawa to investigate automated analysis processes for Communications Electronic Warfare. The aim of the DFACTT system is to automate the collection, correlation and fusion of EW and intelligence data to provide real-time enemy situation estimates and immediate threat warning to the battlefield commander. To achieve this aim, DFACTT employs integrated command, control, and communication functions to automate the complete Electronic Warfare (EW) process. The DFACTT system utilizes EW sensors, such as radio direction finding and intercept systems, and communications equipment fielded by the Canadian Forces. The DFACTT Analyst workstation, designed in an object oriented software environment, provides the automated data reduction and association capabilities and data storage within its database. The raw data and analyzed information are automatically displayed in real-time as icons overlayed on a high resolution topographical map. The EW analyst can access database information directly from the map, or from a text or graphics window. Two of the main system functions are automated sensor data association and reduction, and doctrinal template matching. This document describes advances made in the development of new algorithms and techniques for radio location data analysis and doctrinal template matching.

The DFACTT sensors provide multiple lines of bearing reports on a radio emitter. Triangulation of these lines of bearing generate a number of location estimates. An association algorithm is used to reduce a series of location estimates or fixes into a cluster with a reduced location estimate error term. The data clustering algorithm considers the various emitter fix parameters. The clustering results depend on the time stamp of the signal emission, and the actual location estimate of the emitter and the accuracy of the triangulated fix represented by a confidence ellipse.

Doctrinal Template matching is a form of data analysis that exploits known doctrinal information to identify and determine further information about the physical deployment of the opponent forces. The doctrinal templates used by the DFACTT Analyst Workstation are based on the Electronic Order-of-Battle (EORBAT) of enemy units. The location estimate and unit identification data collected and analyzed by the DFACTT system is complemented and further refined by comparing it to known doctrinal deployments.

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1.0 INTRODUCTION

1.1 Aim

Research was conducted at the Defence Research Establishment Ottawa to develop new reduction, correlation, association, and fusion techniques for the analysis of land Electronic Warfare data. This report presents techniques for radio emitter fix clustering and doctrinal template matching.

1.2 Background

The Data Fusion And Correlation Techniques Testbed (DFACTT) project was developed to automate the data processing necessities of land Electronic Warfare [1]. Two aspects of data analysis are discussed in this paper, radio emitter fix clustering and doctrinal templating.

Radio emitter fix clustering uses data fusion techniques to generate accurate location estimates of enemy radio emitters. The various EW sensors collect data on targeted emitters on the battlefield. This collective information is combined by the clustering method to generate a more accurate estimate of the actual emitter position.

Doctrinal templating is the comparison of collected data about the battlefield situation with the expected layouts of established doctrinal deployments. By matching the estimated deployment with known doctrine it is possible to better estimate the battlefield situation.

1.3 Scope

This report presents the data reduction and fusion algorithms for radio emitter fix clustering and tools developed for doctrinal template matching as part of the DFACTT project.

2.0 DFACTT ANALYST WORKSTATION

The Analyst Workstation provides a work environment for the EW analyst consisting of a map-based user interface, a series of tactical databases, a report generator and control interfaces to the other components of the DFACTT system. The Analyst Workstation automates the analyst's repetitive duties, such as processing incoming data, displaying new information on the tactical map display, tracking friendly radio frequency usage, tracking sensor activity and generating formatted reports. Most important to this report, the Analyst Workstation has capabilities to handle the data reduction, association and correlation to analyze the raw data it receives from the other DFACTT components.

The tactical map display is an intuitive visual representation of the battlefield. The displayable information is overlayed on the map. The map display uses a military UTM grid reference coordinate system that can be set to various scales. A raster scanned topographical image is used as a background. The military units on the battlefield are represented on the tactical map display as friendly or enemy icons. The icons provide direct access to the tactical database. Radio emitter fix clustering manipulations and results are performed from the tactical map display. The doctrinal templating menu options are also available from the tactical map display. An example of the tactical map display is provided in Figure 1.

3.0 RADIO LOCATION DATA ANALYSIS

3.1 Description

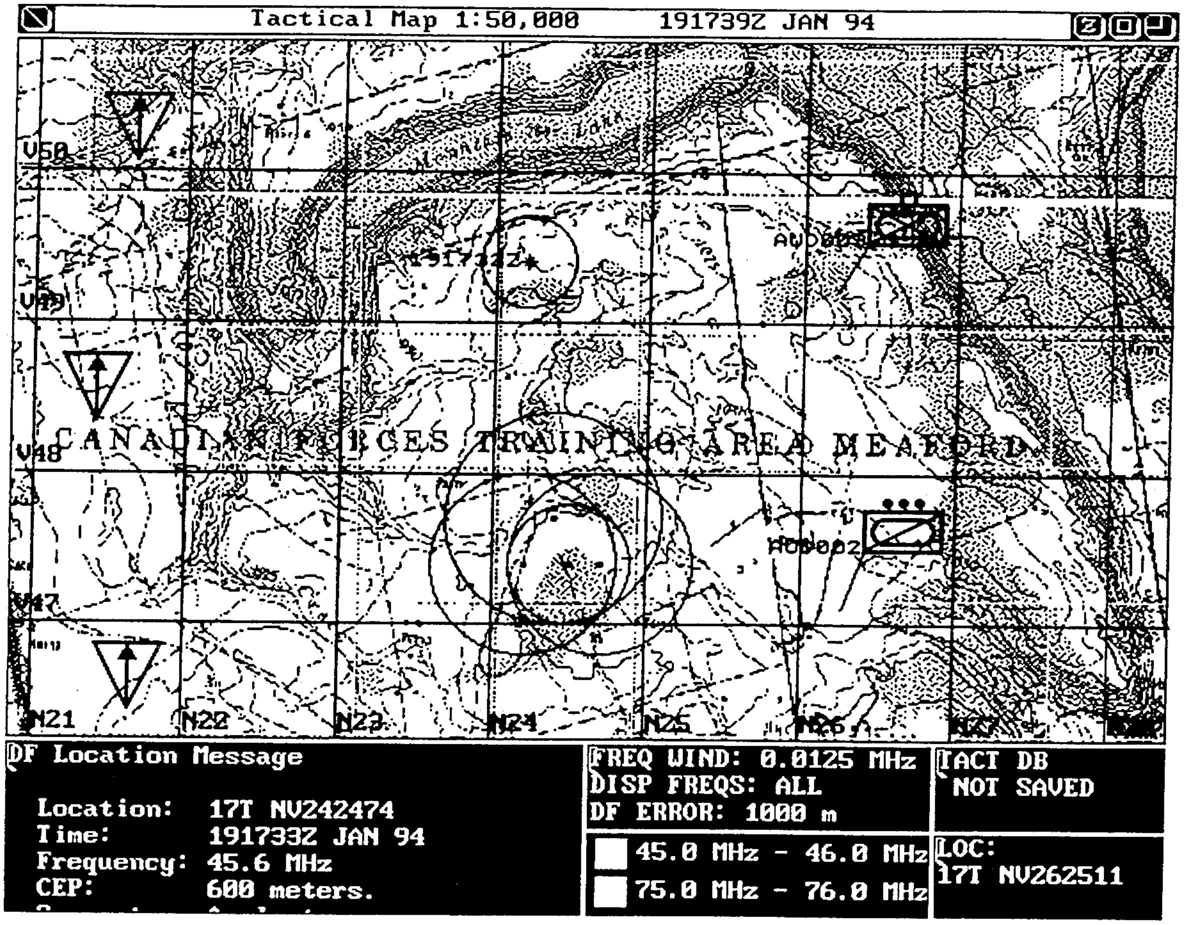
The emitter location data provided to the DFACTT by the radio direction-finding (DF) system consists of a series of emitter fix estimates collected over time. The information provided by these estimates are a two dimensional location vector with a confidence ellipse of the estimate and the radio frequency of the emitted signal with a time stamp. The EW analyst usually wishes to reduce this raw data and produce a more accurate estimate of the emitter's location by clustering multiple fixes.

The user can cluster any or all fix estimates, by highlighting them and selecting the "cluster selected fixes" function from the map menu. All selected fixes are automatically sorted by frequency and time. A clustering test function is then applied to the selected ellipse data for each frequency. The test returns the probability that any two fix estimates were actually generated by the same emitter within a given time frame, and thus the likelihood that they should be clustered. The system then proceeds with fusing all selected fixes that meet the clustering criteria.

This fusion provides a better location estimate for the emitter than the unprocessed collection of fixes. The clustering algorithm provides a better location assessment from multiple location fixes on the same emitter by combining the fixes by weighting their respective error ellipse and time. The result is a cluster located at the weighted mean center of the combined fixes with a reduced error ellipse. An example of clustering emitter fixes is shown in Figure 2.

3.2 Confidence Ellipse

The location estimate supplied to the clustering system



Tactical Map 1:50,000 191739Z JAN 94

DF Location Message

Location: 17T NV242474
Time: 191733Z JAN 94
Frequency: 45.6 MHz
CEP: 600 meters.

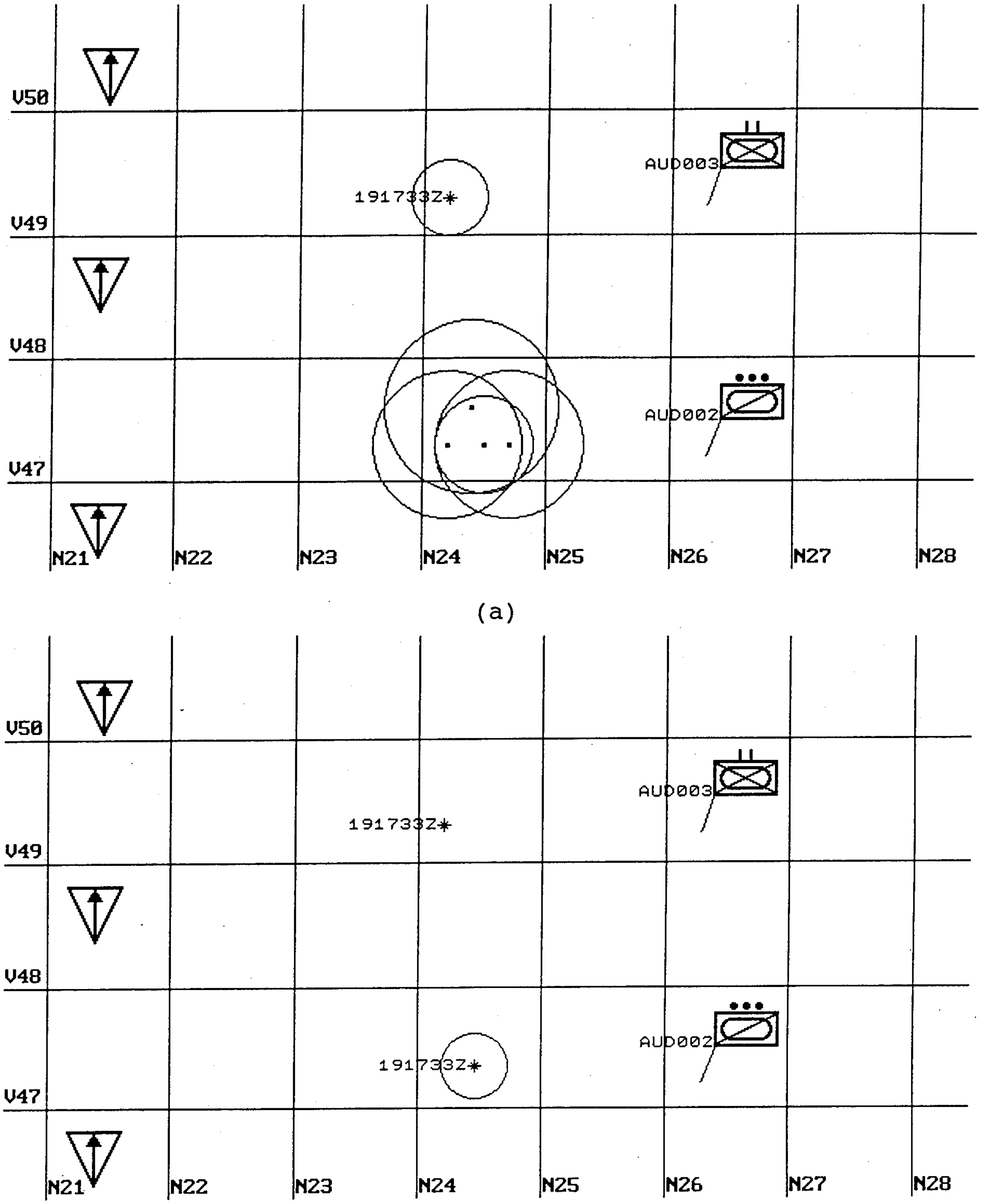
FREQ WIND: 0.0125 MHz
DISP FREQS: ALL
DF ERROR: 1000 m

☐ 45.0 MHz - 46.0 MHz
☐ 75.0 MHz - 76.0 MHz

TACT DB
NOT SAVED

LOC:
17T NV262511

FIGURE 1. DFACTT TACTICAL MAP DISPLAY



(a)

(b)

FIGURE 2. CLUSTERING EMITTER FIXES. (a) Selection of all fixes and clusters, (b) resulting emitter cluster.

represents the mean two dimensional (x and y coordinate) location vector. The confidence ellipse associated with the radio emitter fix estimate represents the variance on this mean value. It is the area in which the emitter can be found for a given probability, usually 50% or 90%. The confidence ellipse is subsequent to the x and y error terms on the fix location estimate.

The location estimate confidence value is representable either geometrically as a confidence ellipse with major axis, minor axis, and rotation with respect to the true north or by a covariance matrix. The confidence ellipse is used as the weight of the location vector in the combination test and the clustering algorithm computation of the new location estimate. The ellipses must be converted to their matrix form for the decision test and fusion, then converted back to geometric form as a cluster.

3.2.1 Covariance Matrix from Ellipse

The geometric representation of the error ellipse provides the major axis, a, the minor axis, b and the orientation θ of the confidence ellipse. The variance-covariance matrix, S, of the ellipse is defined to be [5]:

$$S = \cos\begin{bmatrix} a^2\cos^2\theta + b^2\sin^2\theta & (a^2-b^2)\cos\theta\sin\theta \\ (a^2-b^2)\cos\theta\sin\theta & b^2\cos^2\theta + a^2\sin^2\theta \end{bmatrix} \qquad \textbf{(1)}$$

which is the form necessary to perform the clustering operation.

3.2.2 Ellipse from Covariance Matrix

The clustering algorithm must also determine the ellipse parameters from the resulting cluster covariance matrix. Since the covariance matrix is a symmetric matrix (i.e. $m_{ij} = m_{ji}$ for each matrix entry), this 2x2 matrix contains only three distinct entry values. The parameters to be determined are the major axis, a, the minor axis, b and the orientation θ. The result is a system of three equations and three unknowns. The covariance matrix is represented as:

$$S = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \qquad \textbf{(2)}$$

from which the major and minor axis and the orientation of the clustered ellipse must determined.

3.2.3 Determining Orientation

The orientation of ellipse, θ, can be found first by solving covariance matrix for θ:

$$\frac{2m_{21}}{m_{11}-m_{22}} = \frac{2(a^2-b^2)\cos\theta\ \sin\theta}{a^2\cos^2\theta + b^2\sin^2\theta - b^2\cos^2\theta - a^2\sin^2\theta}$$

$$= \frac{2(a^2-b^2)\ \cos\theta\ \sin\theta}{(a^2-b^2)\ (\cos^2\theta - \sin^2\theta)}$$

$$= \frac{2\cos\theta\ \sin\theta}{\cos^2\theta - \sin^2\theta} \tag{3}$$

$$= \frac{\sin 2\theta}{\cos 2\theta}$$

$$\frac{2m_{21}}{m_{11}-m_{22}} = \tan 2\theta$$

Therefore:

$$\theta = \frac{1}{2}\ atan\left(\frac{2m_{21}}{m_{11}-m_{22}}\right) \tag{4}$$

A special case of this would be when $m_{11} = m_{22}$. This would mean

$$\begin{aligned} &a^2\cos^2\theta + b^2\sin^2\theta = b^2\cos^2\theta + a^2\sin^2\theta \\ &(a^2 - b^2)\ \cos^2\theta = (a^2 - b^2)\ \sin^2\theta \\ &\cos^2\theta = \sin^2\theta \end{aligned} \tag{5}$$

θ is restricted to: $\pi \leq \theta \leq 0$, so $\theta = \pi/4$ or $\theta = 3\pi/4$

If, on the other hand, the equality $m_{11} = m_{22}$ results from a = b, then the ellipse degenerates into a circle and the value of θ can be set to anything.

3.2.4 Determining Axes

Once θ is known, the major or minor axis can be determined. In solving for either axis it should be noted that there is a special case when $\sin 2\theta = 0$. Then $2\theta = 0$ or π, so $\theta = 0$ or $\pi/2$. If $\theta = 0$ then $a = \sqrt{m_{11}}$ and $b = \sqrt{m_{22}}$. Similarly, when $\theta = \pi/2$ then $b = \sqrt{m_{11}}$ and $a = \sqrt{m_{22}}$.

The minor axis b is determined by:

$$\sqrt{\frac{m_{11}+m_{22}}{2} - \frac{m_{21}}{\sin 2\theta}} = \sqrt{\frac{(a^2+b^2)(\cos^2\theta+\sin^2\theta)}{2} - \frac{(a^2-b^2)}{2}}$$

$$= \sqrt{\frac{(a^2+b^2-a^2+b^2)}{2}} \tag{6}$$

$$= \sqrt{\frac{2b^2}{2}}$$

$$\sqrt{\frac{m_{11}+m_{22}}{2} - \frac{m_{21}}{\sin 2\theta}} = b$$

The major axis, a, can then be solved, assuming b is already determined.

$$\sqrt{m_{11}+m_{22}-b^2} = \sqrt{(a^2+b^2)-b^2}$$

$$\sqrt{m_{11}+m_{22}-b^2} = \sqrt{a^2} \tag{7}$$

$$\sqrt{m_{11}+m_{22}-b^2} = a$$

3.3 Correlating Emitter Ellipses

When the EW analyst selects a number of emitter fixes to be clustered, the system must determine which emitter ellipses should be clustered together. This correlation is based on the frequency, time, and location of each emitter fix.

A collection of fixes could be portrayed as:

FIX1	frequency1	time1	location1
FIX2	frequency2	time2	location2
FIX3	frequency1	time3	location3
FIX4	frequency2	time4	location4
FIX5	frequency1	time5	location5
FIX6	frequency3	time6	location6

where it is assumed that only one fix can be taken at a given instant in time and that it is unlikely that two fixes would have exactly the same location and error ellipse. All selected fixes are first sorted by frequency, then grouped in pairs by time:

```
FIX1 frequency1 time1 location1
FIX3 frequency1 time3 location3

FIX5 frequency1 time5 location5


FIX2 frequency2 time2 location2
FIX4 frequency2 time4 location4

FIX6 frequency3 time6 location6
```

In this example FIX1 and FIX3 would first be tested for correlation in time and then in location. If the two fixes met the respective confidence thresholds they would be clustered. FIX5 would then be tested for correlation with the frequency1 cluster in a similar fashion.

3.3.1 Time Correlation

In the DFACTT system, emitter fixes have an associated time stamp based on when the data was collected. Because radio emitters often move on the battlefield, the more recent emitter data has a higher confidence. In the current implementation, the level of confidence decays exponentially with time, to model the "aging" of the data. This "age" is used to determine whether two ellipses should be combined or not. The DFACTT uses the relative time between two candidate ellipses for time correlation, not the current real time of the system. This is to allow the EW analyst to examine situations at the time they occurred not at the moment of analysis.

The time correlation test is used to determine if a new emitter ellipse should be added to an existing ellipse or cluster based on their relative ages. A cluster has a time range encompassing the time stamps of all the fixes that have been fused to form the current ellipse. When a fix is to be added to an existing cluster the cluster is treated as an ellipse using its most recent time stamp. The time correlation test treats the time stamp of a cluster and a fix equally. The user specifies a maximum time range over which it may be assumed that two emissions, on the same frequency and from the same approximate location (assuming the locations correlate), belong to the same emitter. Let E_1 and E_2 be two ellipses with time stamps t_1, t_2 respectively, and the specified time range be t_r. The time correlation test $T(E_1,E_2)$ is given by:

$$T(E_1, E_2) = e^{\frac{-|t_1 - t_2|}{t_r}} \quad \textbf{(8)}$$

The result is compared to a time confidence threshold, C_T (a value representing the confidence that the two fixes originated from the same emitter). The value of the time range and the confidence threshold can be determined empirically, or arbitrarily set by the user. Example values used in DFACTT are a time range of ten minutes and a confidence threshold of 50%.

3.3.2 Location Correlation

Given two point estimates, represented by confidence ellipses, the location correlation test determines the confidence level to which they represent the same source, geometrically. The value of the acceptance statistic is usually compared to a given confidence threshold C_L, i.e., 50%. Let E_1 and E_2 be two fix confidence ellipses, let v_1 and v_2 be the coordinates of their centres, and let S_1 and S_2 be their variance-covariance matrices. The location correlation test statistic, denoted by $L(E_1, E_2)$ is given by [5]:

$$L(E_1, E_2) = (v_1 - v_2)^T(S_1 + S_2)^{-1}(v_1 - v_2) \quad \textbf{(9)}$$

If the location confidence level exceeds the threshold C_L and the time confidence level exceeds the threshold C_T, the two emitter fixes will be clustered.

3.4 Clustering Emitter Fixes

Emitter fixes are clustered by combining their confidence ellipses. Let $\oplus$ denote the combination operator. To represent the resulting ellipsis of the combined ellipses $E_1 \oplus E_2 \oplus \ldots \oplus E_n$, the variance-covariance matrix and the centre point are sufficient. The resulting variance-covariance matrix is given by [5]:

$$S_1 \oplus S_2 \oplus \ldots \oplus S_n = (S_1^{-1} + S_2^{-1} + \ldots + S_n^{-1})^{-1} \quad \textbf{(10)}$$

and the resulting centre point is given by:

$$E_1 \oplus \ldots \oplus E_n = (S_1 \oplus \ldots \oplus S_n)(S_1^{-1}v_1 + \ldots + S_n^{-1}v_n) \qquad \textbf{(11)}$$

It can be shown that the combination operator $\oplus$ is commutative and associative [6]. From the associative and commutative properties of $\oplus$ we can deduce that combining a set of ellipses will result in the same ellipse, independent of the combination order. Once the resulting ellipse is calculated in matrix form it is converted back into geometric form, using equations 4 through 7, as a confidence ellipse with major axis, minor axis, and rotation with respect to the true north.

The emitter cluster represents a more accurate estimate of an emitter's location than the individual fixes of which it is comprised. This cluster is realised as an object in the DFACTT that can be stored, displayed, identified as an emitter or unit, tracked over time, and correlated with intercepted radio traffic.

4.0 DOCTRINAL TEMPLATING

The Doctrinal Templating feature of the DFACTT Analyst Workstation assists the EW analyst in identifying the battlefield formations of the opponent forces using the tactical map. The doctrinal templates used by the DFACTT Analyst Workstation are based on the Electronic Order-of-Battle (EORBAT) of an opposing force [10]. The Analyst Workstation maintains databases of known battlefield deployments or templates. It also allows the user to create new "working" templates based on the current estimate of the opposing force's EORBAT. These working templates help identify a change in a given tactical deployment relative to the previous deployment estimate. Previously the analyst had to rely on his visual matching ability to identify EORBAT templates [2]. The DFACTT Analyst Workstation now uses automated algorithms for matching both doctrinal and working templates to the estimated battlefield situation.

Doctrinal Templating compares the deployment templates from the Doctrinal Database to the units on the Tactical Map. The comparisons result in a confidence factor value for the template match. The templating match results are listed in the Templating Match Browser. The match results for the individual units for a template are listed in the Element Match Result Browser.

The template matching algorithm determines the best matches between the individual units of the template and the opponent units on the tactical map. The matching pairs are selected by a "greedy" algorithm, they are chosen in order of best confidence factor for the pair match.

All the known battlefield information can be displayed on the Tactical Map. The displayable items include the opponent units and the templates. Furthermore, new templates can be created from the tactical map. All template icons are displayed using standard military symbology [9] to aid the EW analyst in identifying the opponent force disposition. An example of doctrinal templating using the tactical map (with no background) is show in Figure 3.

4.1 DFACTT Templating Functions

Doctrinal Templating is invoked from the Tactical Map display of the DFACTT Analyst Workstation. For more information about the Doctrinal Templating user interface please consider reference [4]. The templating options allow the user to create, delete or display a template on the tactical map, or to match a template against selected opponent icons on the tactical map. The matching options are available from the DFACTT Templating menu. The user may match a collection of templates from the Working or Doctrinal Database, or match a specific template selected by name from the templating databases, or directly from the tactical map display.

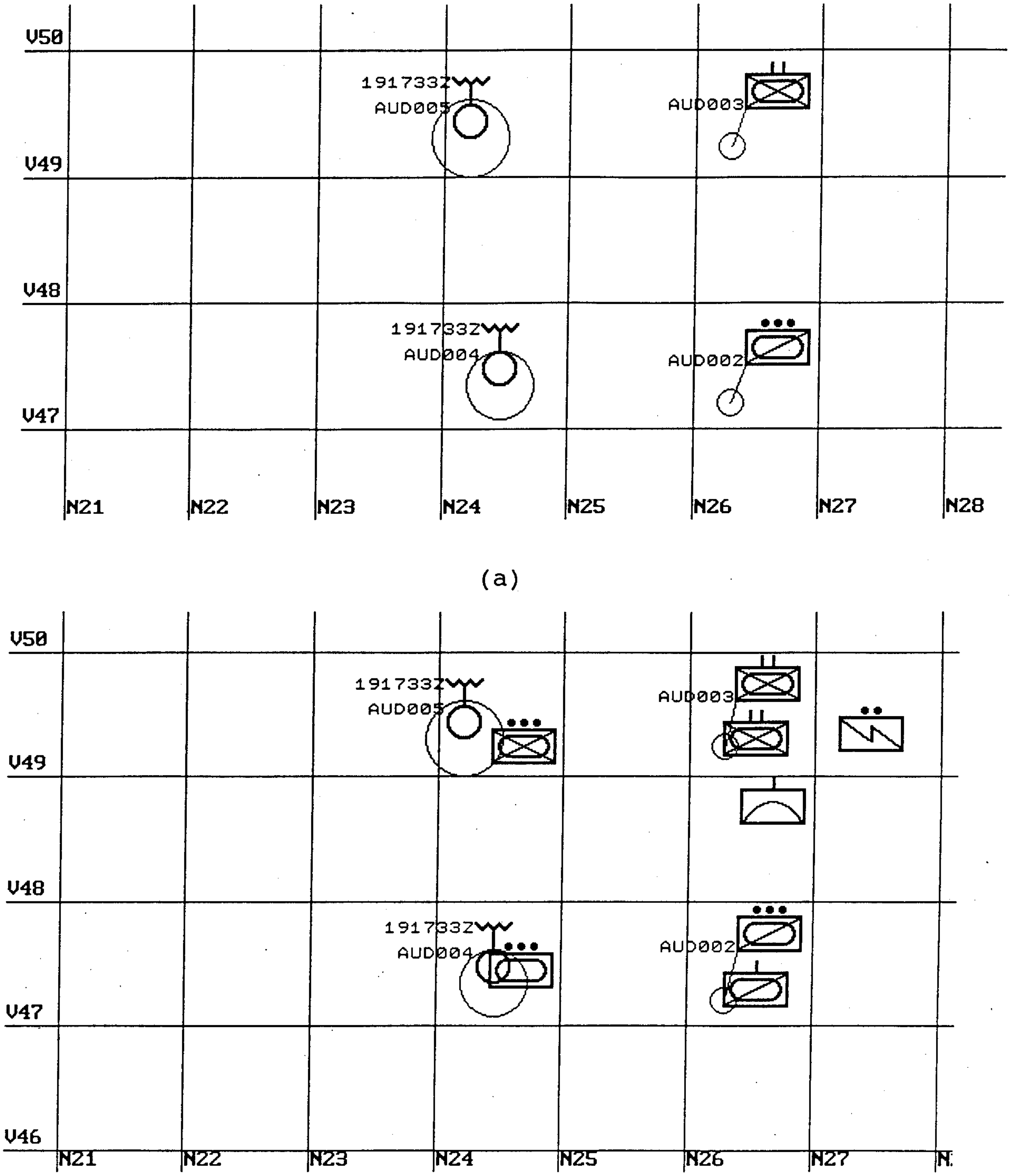
For each template match, the user is prompted, by a crosshair cursor, for the hypothesized location of the headquarters command post of the template on the tactical map. The user is also prompted for the orientation of the template on the tactical map. The orientation is specified by the number of degrees in a clockwise direction. Each templating match also generates a match result browser.

4.1.1 Matching Templates from a Database

All the templates in the chosen database are matched against the selected units on the tactical map display. The templating databases available are the Doctrinal Templating Database and the Working Templating Database. The match will generate a Template Match Result browser in which all the templates in the database are shown in decreasing order of Combined Confidence Factor match value.

4.1.2 Matching a Selected Template from a Database

This option matches only one specific template selected from one of the templating databases. It is used when the EW analyst wishes to match the tactical situation to a specific template. For example, the EW analyst believes the unit disposition he has determined from sensor data represents a river crossing by the opponent force and wishes to verify his hypothesis. The analyst



(a)

(b)

FIGURE 3. DOCTRINAL TEMPLATING USING MAP DISPLAY. (a) Opponent force disposition determined from EW sensor data, (b) a matching doctrinal template overlayed on map.

would try to match only a "river crossing" template to the selected units. The match generates a Match Result Browser, listing the result of the template match.

4.1.3 Matching Selected Command Posts

The templates corresponding to the selected command posts on the tactical map display are matched against the selected opponent units. The match generates a Match Result Browser in which the match results for the selected command post templates are listed.

4.1.4 Displaying a Template on the Map

The DFACTT Analyst user may display a chosen template from the templating databases. Similarly to template matching, the user is prompted for the orientation and location of the template. The user can also modifying the Template Databases. The user is given the option to add, edit, or remove templates from the Doctrinal and Working databases.

4.2 Templating Browsers

Template matching calculates the match parameters and confidence factor for the matching templates and opens up a Template Match Result Browser to list them. The matches for each individual element are listed in the Element Match Result Browser.

4.2.1 Template Match Result Browser

This Browser, shown in Figure 4, lists the results of the template matches. The browser consists of a list pane that lists the template names and a text pane that describes the template match values. The templates are listed in order of best to worst Confidence Factor match value. The description pane displays the template match parameters:

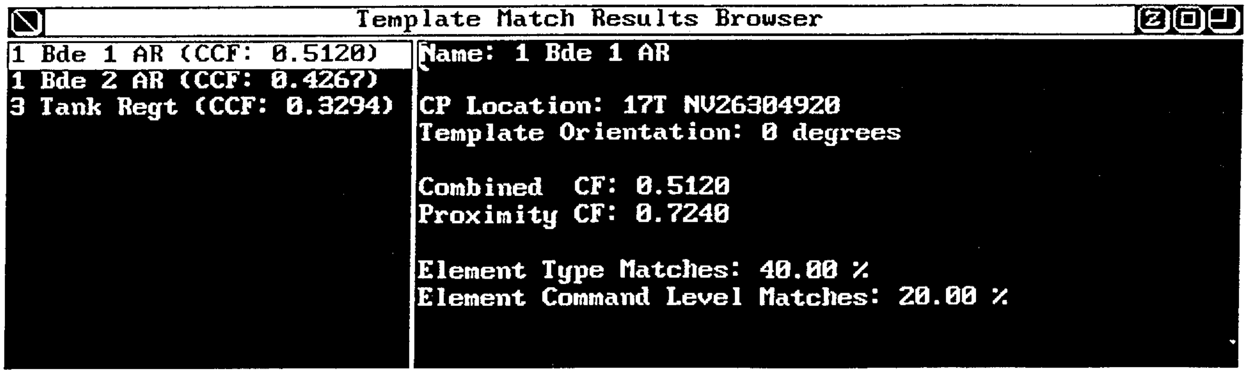
* the combined confidence factor for the template match

* the proximity confidence factor for the template match

* the percentage of command level matches between the template and opponent units

* the percentage of unit type matches between the template and opponent units

The Template Match Result Browser also provides a menu for the templates listed in the browser. The user may display a template on the tactical map, remove the template if it is displayed and he may also open up an Element Match Result browser to inspect



```
1 Bde 1 AR (CCF: 0.5120)
1 Bde 2 AR (CCF: 0.4267)
3 Tank Regt (CCF: 0.3294)
```

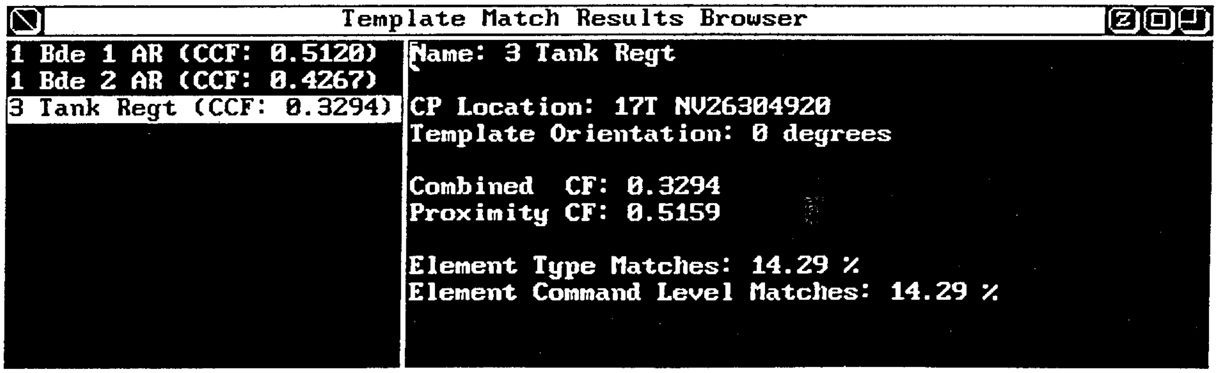
```
Name: 1 Bde 1 AR

CP Location: 17T NV26304920
Template Orientation: 0 degrees

Combined  CF: 0.5120
Proximity CF: 0.7240

Element Type Matches: 40.00 %
Element Command Level Matches: 20.00 %
```

(a)



```
1 Bde 1 AR (CCF: 0.5120)
1 Bde 2 AR (CCF: 0.4267)
3 Tank Regt (CCF: 0.3294)
```

```
Name: 3 Tank Regt

CP Location: 17T NV26304920
Template Orientation: 0 degrees

Combined  CF: 0.3294
Proximity CF: 0.5159

Element Type Matches: 14.29 %
Element Command Level Matches: 14.29 %
```

(b)

FIGURE 4. TEMPLATE MATCH RESULT BROWSER. (a) Selection of a template with a high confidence to match the situation in Figure 3, (b) a lower confidence match.

the individual element matches between the template and the opponent units on the tactical map.

4.2.2 Template Match Result Browser Computations

The proximity confidence factor for the template match is the average of the individual template to opponent unit match proximity confidence factors. The proximity confidence factor value represents the probability of the template match considering the template unit locations with respect to the selected opponent unit locations.

The combined confidence factor for the template is, again, the average of the individual template to opponent match combined confidence factors. The combined confidence factor value represents the probability of the template match. This value was obtained by considering all the known parameters of the template and opponent units.

The Template Match Result Browser text pane also indicates the percentage of unit type matches and the percentage of command level matches.

4.2.3 Element Match Result Browser

The Element Match Result Browser, shown in Figure 5, lists the template element to tactical element pairings. The browser is made up of the element list pane, the element description pane, and the pair combined description pane.

The element list pane either lists the template units or the opponent (tactical) units. The units are identifiable by their parameters. The element description pane shows either the template element parameters or the opponent (tactical) element parameters. The element description toggle button (at the bottom of each pane) alternates the element description pane between the template element and the opponent element states. The combined description pane lists the parameters of the match between the template unit and the opponent unit. The match parameters are the proximity confidence factor, the combined confidence factor, the command level match value and the type match value. The match values are either true or false.

Figure 5(a) shows a high confidence match of the command post element for the template "1 Bde 2 AR" (1st Brigade, 2nd Armour Regiment) to the tactical command post element AUD003 (Arbitrary Unit Designator 003) from the map in Figure 3. Figure 5(b) displays the template element for which there is no matching tactical element. In this example, the template indicates that there should be an air defence battery deployed near the HQ that is not present in the tactical data. Figure 6 illustrates how the EW analyst would use template data to help identify emitters

Element Match Results Browser for Template: 1 Bde 2 AR

```
Infantry Battalion (CCF: 0.9618)
Reconnaissance Squadron (CCF: 0.7
atoon (CCF: 0.4856)
Infantry Platoon (CCF: 0.4639)
ce Battery (CCF: 0.0000)
ction (CCF: 0.0000)
```

```
Unit  -  ID:  AUD003

 Networks:  unknown
 Callsigns:  unknown
 Frequencies:  unknow
 Nodes:  AUD003
 Last heard:
```

```
 Combined  CF: 0.9618
 Proximity CF: 0.9235

 Type Match: true
 Command Level Match:
```

(a)

Element Match Results Browser for Template: 1 Bde 2 AR

```
Armoured Infantry Battalion (CCF:
Armoured Reconnaissance Platoon ((
 (CCF: 0.4856)
 (CCF: 0.4639)
 - no match -   (CCF: 0.0000)
 - no match -   (CCF: 0.0000)
```

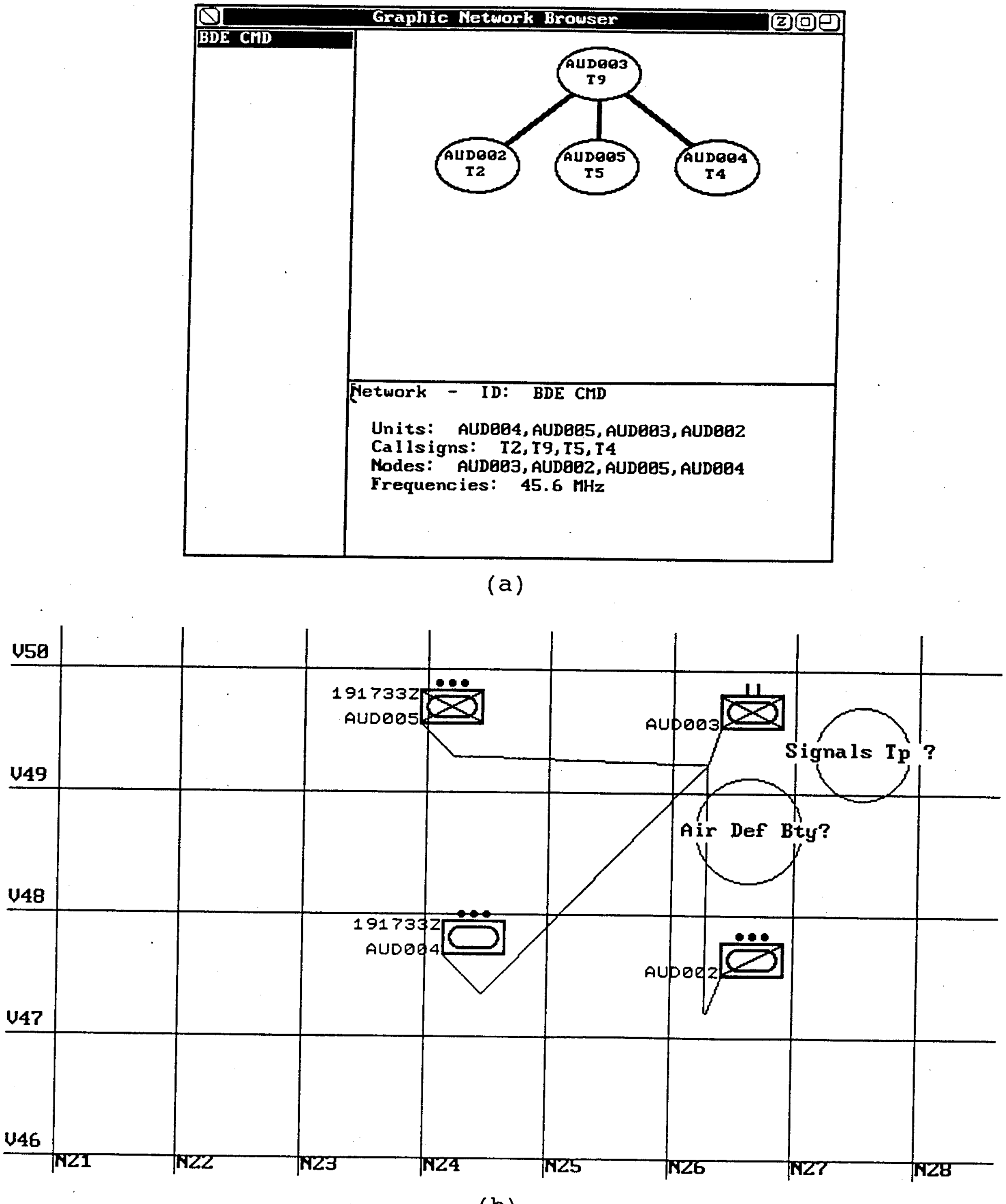
```
UNIT: Air Defence
COMMAND LEVEL: Battery
TEMPLATE: 1 Bde 2 AR
COMMAND POST: No
```

```
 Combined  CF: 0.0000
 Proximity CF: 0.0000

 Type Match: false
 Command Level Match:
```

(b)

FIGURE 5. ELEMENT MATCH RESULT BROWSER. (a) Displaying a successful match of a template element to a tactical element, (b) displaying the template element for which there is no matching tactical element.



Network - ID: BDE CMD

Units: AUD004,AUD005,AUD003,AUD002
Callsigns: T2,T9,T5,T4
Nodes: AUD003,AUD002,AUD005,AUD004
Frequencies: 45.6 MHz

(a)

(b)

FIGURE 6. USE OF TEMPLATING TO IDENTIFY EORBAT. (a) Communication network identified from sensor data, (b) identification of detected units and possible undetected units from template.

already detected (Figure 3) and direct his search for other possible units.

4.3 Proximity Confidence Factor

The proximity confidence factor for an element match is calculated using a normal distribution with zero mean. The standard deviation σ varies with the command level of the template element and can also be modified by the user. The proximity confidence factor, pcf, is given by:

$$pcf = e^{-\frac{r^2}{2\sigma^2}} \tag{12}$$

4.4 Combined Confidence Factor

The combined confidence factor is calculated using a weighted average of the proximity confidence factor, p, with a weight of 1; the type match, t, (t=0 when not matched and t=1 when matched) with a weight of w_t and the command level match, l, (again with possible values of l=0 or l=1) with a weight of w_l. The formula for the combined confidence factor, ccf, is:

$$ccf = \frac{p + (t \cdot w_t) + (l \cdot w_l)}{1 + w_t + w_l} \tag{13}$$

4.5 Template Matching Algorithm

The template pair choices are made by considering the combined confidence factors for each possible template unit and opponent (tactical) unit combination. The pairs are selected by choosing the highest combined confidence factor pair out of the unmatched template elements and tactical elements until every element is either matched or excluded. If there are more template elements than tactical elements, then there will be template elements excluded from the match. Similarly, if there are more tactical elements than template elements then there will be tactical elements excluded from the match. These excluded elements are paired with a nil tactical element (or nil template element), have a combined and proximity confidence factor of 0 and contribute this value to the combined and proximity confidence factor for the whole template match.

5.0 CONCLUSION

The error ellipse clustering calculations have been optimized by using correlation criteria based on the frequency, time, and location of each emitter fix. The fusion of multiple emitter fixes into a cluster results in a more accurate estimate of an emitter's location than the collection of individual fixes. The cluster also represents a more current estimate of the emitter's location since the correlation criteria employs an aging process on emitter data. This cluster is realised as an object in the DFACTT that can be stored, displayed, identified, tracked over time, and correlated with intercepted radio traffic.

The DFACTT Analyst's template matching capability aids the analyst by adding a computed match probability value to the template match, where previously the analyst had to rely on his visual matching ability only. The analyst can now efficiently and correctly find the closest matching template from a vast collection of template candidates in a very short time. The EW analyst can use template data to help identify units already detected, direct the search for possible undetected units, and determine the opponent force disposition on the battlefield.

The electronic battlefield is both complex and dynamic. The DFACTT provides tools to help process the vast amounts of data collected by a modern tactical SIGINT system. However, human knowledge, experience, and intuition are still the most reliable analysis tools. Error ellipse clustering and doctrinal templating support the EW analyst by handling the brute force data correlation, association and fusion work, leaving room for the analyst's finer decisions.

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